Physics Opportunities with High Intensity Accelerators

The Six Accelerator Capability areas:

- Energy Frontier Hadron Colliders
- Energy Frontier Lepton and Gamma Colliders
- High Intensity Secondary Beams Driven by Protons
- High Intensity Electron and Photon Beams
- Electron-ion Colliders
- Accelerator Technology Testbeds and Test Beams

Example Acc. Sources:

- Neutrino super-beams
- Project-X
- Beta-beams
- DAEδALUS & pion DAR
- IsoDAR (isotope DAR)
- Neutrino Factory

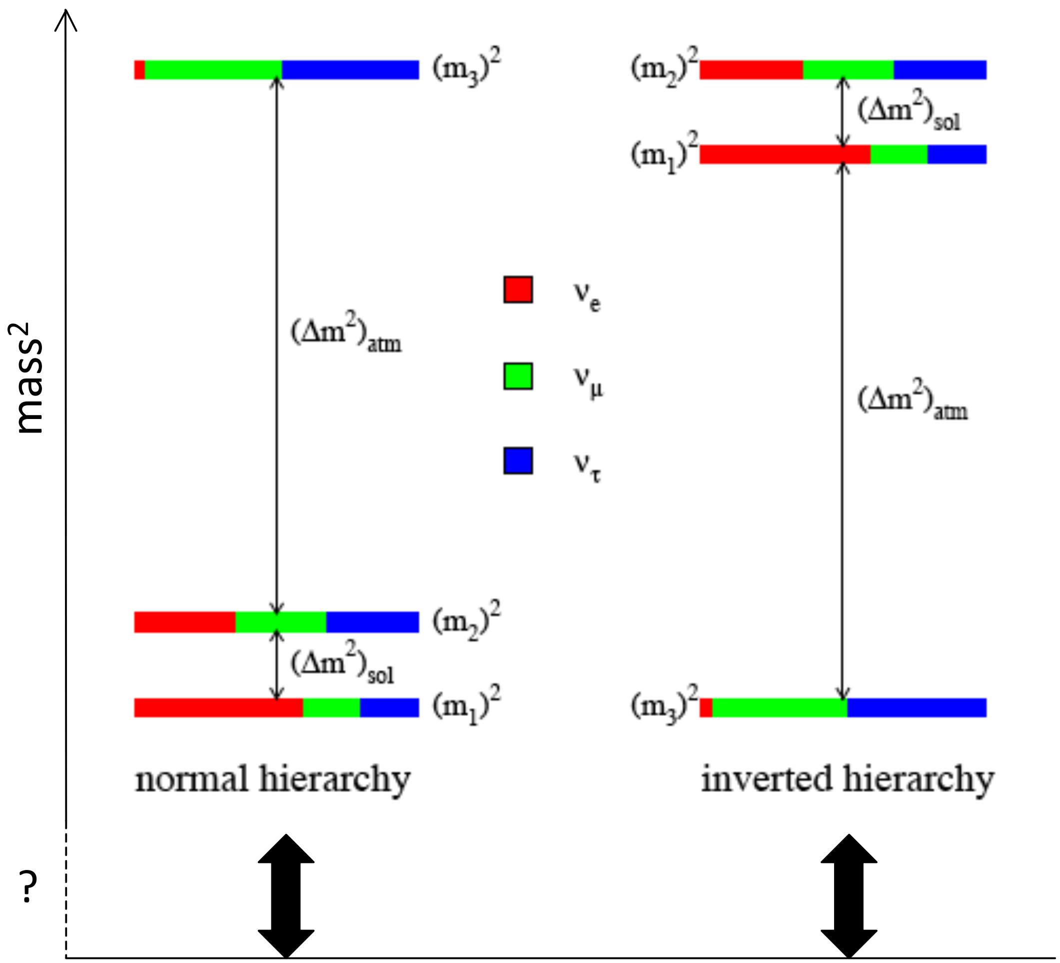
Example Physics:

- Neutrino 3-flavor mixing
- Sterile neutrino hints
- Other weakly interacting and dark sector particles
- Non-standard neutrino interactions

Neutrino 3-flavor Mixing ⇒ Precision Measurement Era

$$U_{PMNS}^{2013} = \begin{pmatrix} 0.779\ to\ 0.848 & 0.510\ to\ 0.604 & 0.122\ to\ 0.190 \\ 0.183\ to\ 0.568 & 0.385\ to\ 0.728 & 0.613\ to\ 0.794 \\ 0.200\ to\ 0.576 & 0.408\ to\ 0.742 & 0.589\ to\ 0.775 \end{pmatrix}$$

Neutrino mixings now known with similar error to 1995 quark mixings.



Beyond neutrino mixings:

- Need to determine "Mass Hierarchy"
  - Use long baseline experiments through matter effects (i.e. LBNE)
- Need to determine and measure "CP Violation"
  - Key question for the physics of neutrino mixing (also maybe Leptogenesis)
  - Difficult: need precision oscillation measurements

Key Experimental Requirements

- Beam (neutrino/antineutrino source) intensity
  - Statistics at a premium (especially for $\bar{\nu}$ running)
  - Need good understanding of flux and flavor components
- Detector size and efficiency
  - Larger size can impact cost and detection efficiency
- Control of systematic uncertainties
  - Need to fit shape of event energy distribution
    - Energy dependence of flux, backgrounds, and efficiency
  - Need to compare ν versus $\bar{\nu}$ distribution
    - May be complicated by ν contamination in $\bar{\nu}$ running

Examples

LBNE: Fermilab to South Dakota

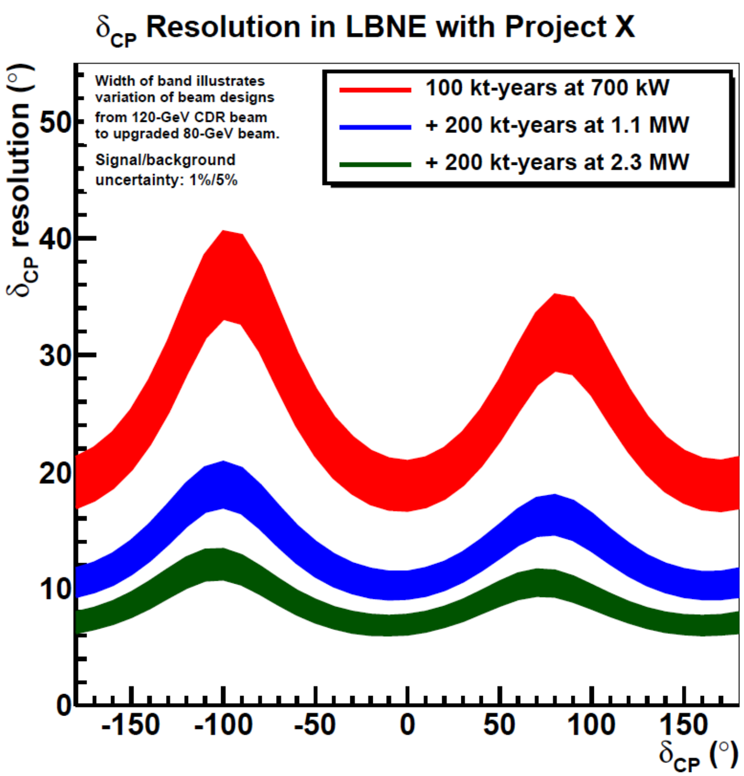
- 35 kton Liquid Argon - 700kW to 1200kW beam power
- Optimum 1300km distance for on-axis pion decay-in-flight
- Significant matter effects

Hyper-K: J-PARC to Hyper-K

- 560 kton water cherenkov - 750kW beam power
- Off-axis 295km distance
- Small matter effects

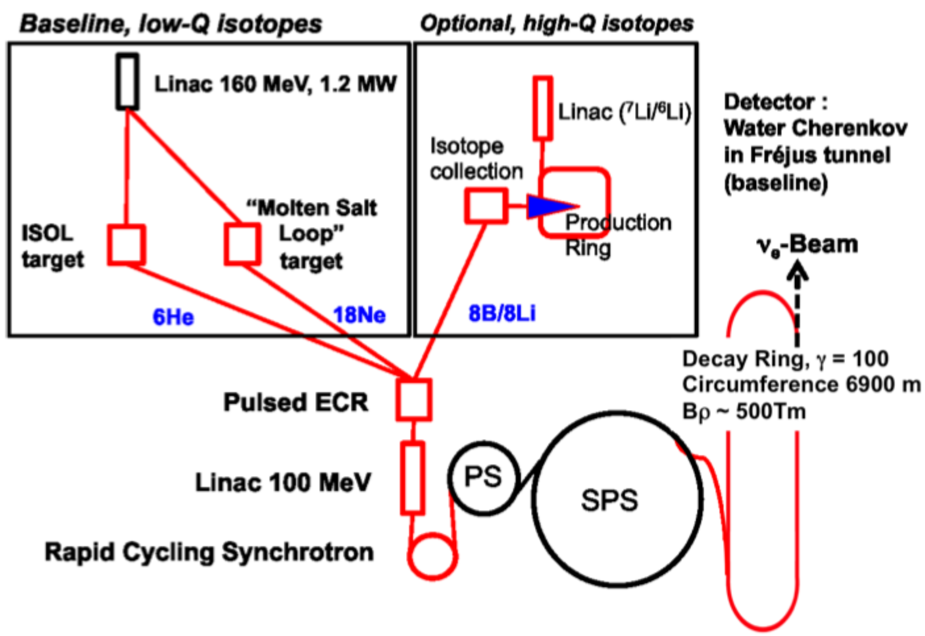
Improvements with Better Accelerator Sources

Project-X:
x3 improved intensity for LBNE
(0.7MW → 1.1MW → 2.3MW)



Beta-Beams:
Pure ν_e and $\bar{\nu}_e$ beams generated by the β-decay of accelerated radio-nuclides stored in a high energy storage ring.

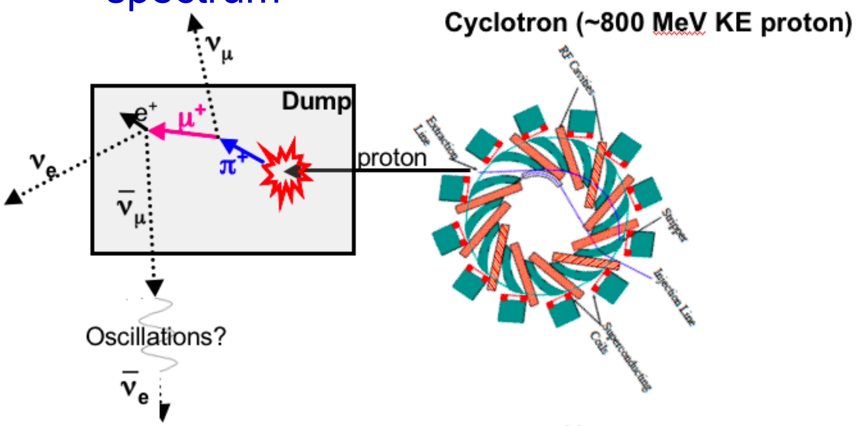
– Measure $\nu_e \rightarrow \nu_\mu$ oscillations



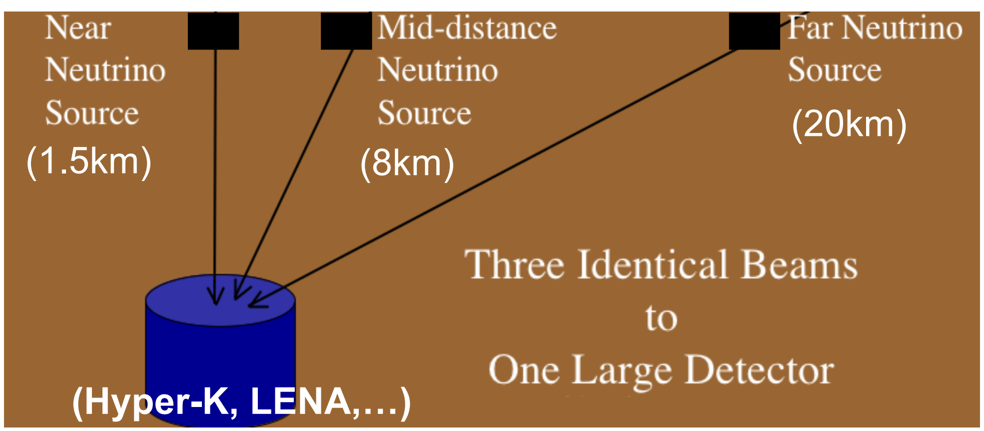
Improvements with Better Accelerator Sources (2)

DAEδALUS:

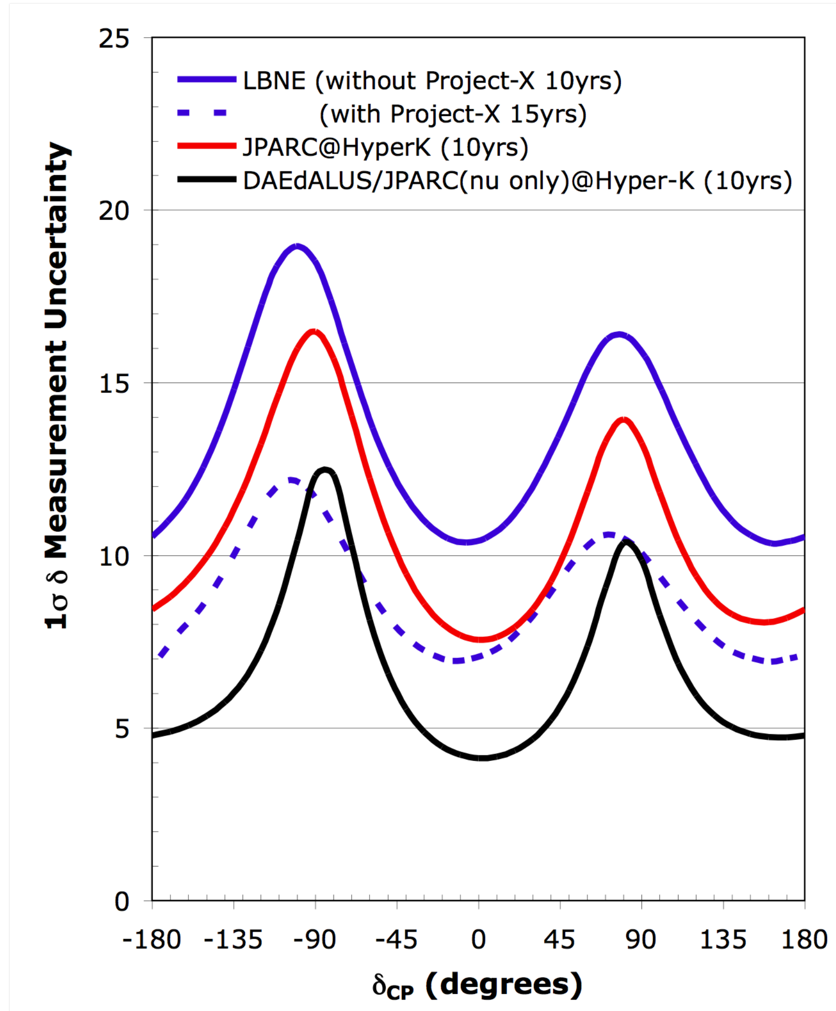
- Pion decay-at-rest neutrino source produced by high-intensity cyclotron
  - Very high-intensity $\bar{\nu}_\mu$ source with known spectrum



- Neutrino sources at three different distances
  - Use inverse-beta-decay interaction to isolate a pure sample of $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations

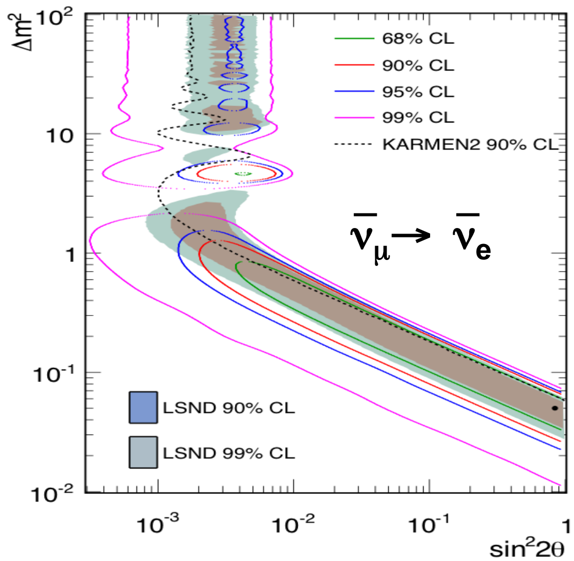


- Can combine DAEδALUS antineutrino data set with long baseline neutrino-only data for much improved CP violation search
  - Example: combination with Hyper-K



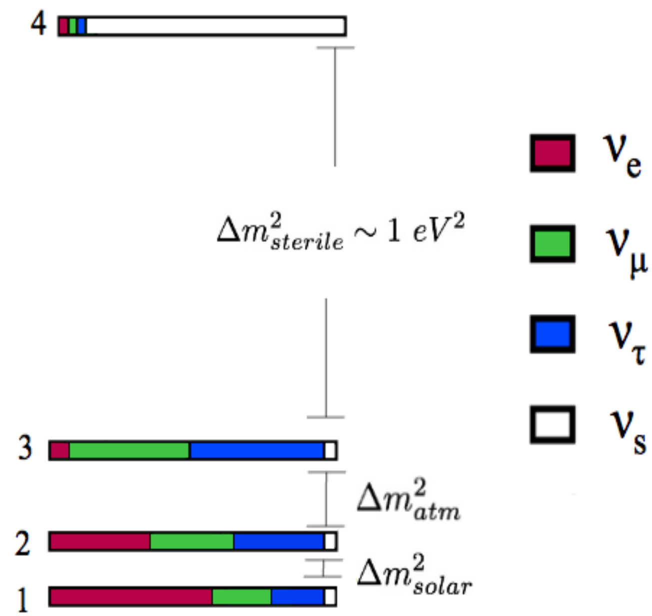
Collection of Data That Doesn't Fit 3-neutrino Model $\Rightarrow$ Sterile Neutrinos?

- MiniBooNE/LSND ν_e / $\bar{\nu}_e$ appearance signals

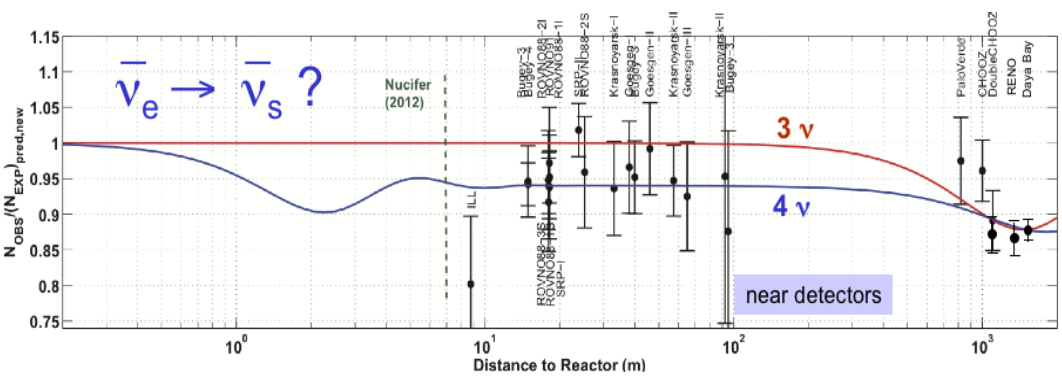


Data sets indicate a high Δm^2

Can be fit by introducing a new ν,
…but it must be non-interacting (sterile)!



- Reactor Anomaly: $\bar{\nu}_e$ disappearance signals?

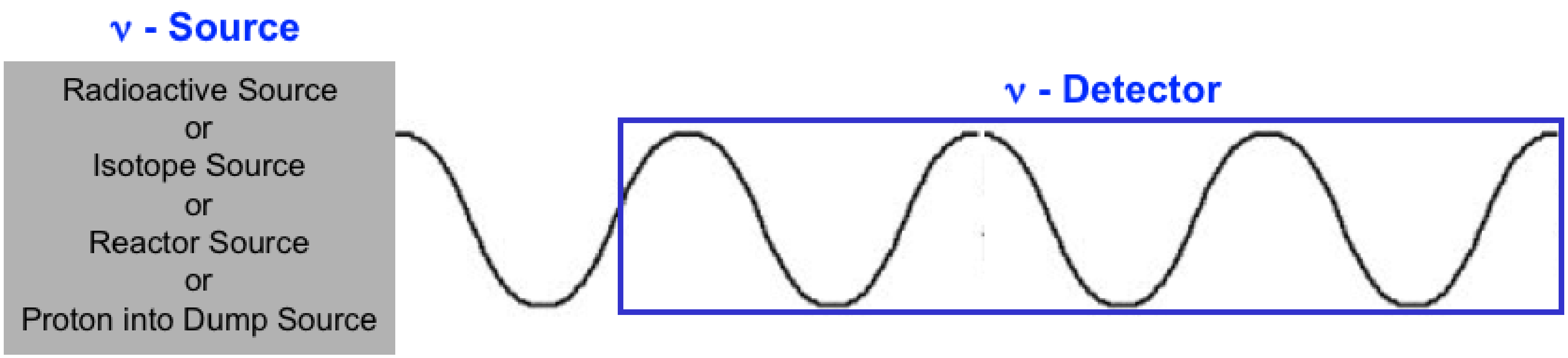


These signals are at the 2-4σ level $\Rightarrow$ Need new "definitive" experiments

Establishing the existence of sterile neutrinos would be a major result for particle physics

Probing $\Delta m^2 \sim 1\ eV^2$ Oscillations

Short and Very-short Baseline Oscillation Experiments



- Need definitive experiments
  - Significance at the > 5σ level
  - Smoking gun: Observation of oscillatory behavior within detector
- Several directions for next generation accelerator experiments
  - Multi-detector accelerator neutrino beam experiments
  - Very short baseline (VSBL) experiments with compact neutrino sources

- Many ideas and neutrino sources:
  - Reactor sources
  - Radioactive sources
  - Isotope sources
  - π / K decay-at-rest sources
  - π decay-in-flight sources
  - Low-energy ν-Factory source


arXiv.org > hep-ph > arXiv:1204.5379

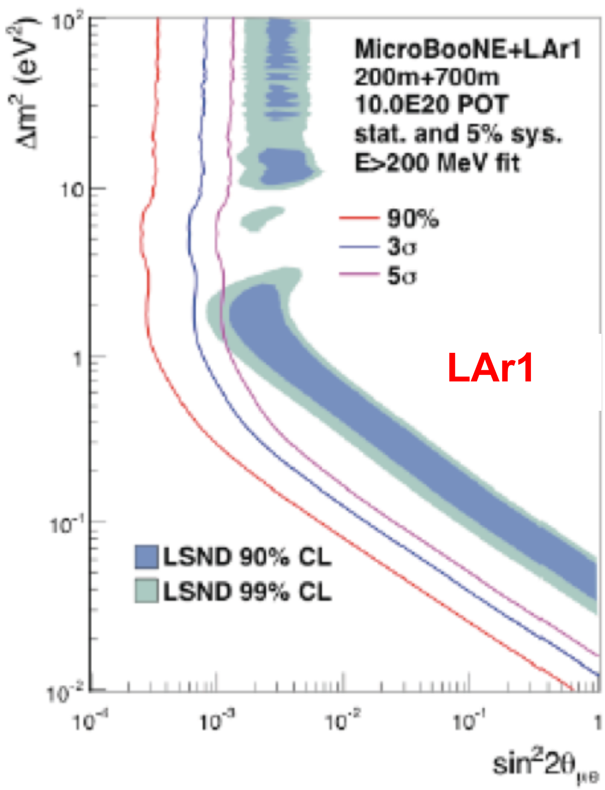
High Energy Physics – Phenomenology

Light Sterile Neutrinos: A White Paper

K. N. Abazajian, M. A. Acero, S. K. Agarwalla, A. A. Aguilar-Arevalo, C. H. Albright, S. Antusch, Barenboim, V. Barger, P. Bernardini, F. Bezrukov, O. E. Bjaelde, S. A. Bogacz, N. S. Bowden, A. B Brice, A. D. Bross, B. Caccianiga, F. Cavanna, E. J. Chun, B. T. Cleveland, A. P. Collin, P. Coloma, J. C. D'Olivo, S. Das, A. de Gouvea, A. V. Derbin, R. Dharmapalan, J. S. Diaz, X. J. Ding, Z. Djurci R. Elliott, D. J. Ernst, A. Esmaili, J. J. Evans, E. Fernandez-Martinez, E. Figueroa-Feliciano, B. T. F Gaffiot, R. Gandhi, Y. Gao, G. T. Garvey, V. N. Gavrin, P. Ghoshal, D. Gibin, C. Giunti, S. N. Gnine shown)

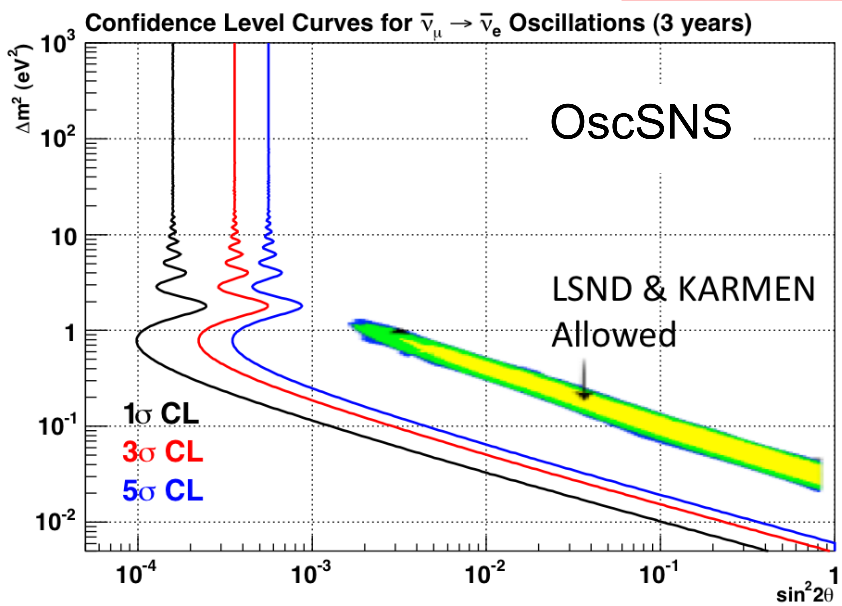
Improvements with Better Accelerator Sources

- Short baseline pion decay-in-flight beams
  - Project-X could provide an enhanced replacement to the existing Booster-Neutrino Beam
  - Multi-detector (near-mid-far) provide definitive sterile osc searches
    - LAr1: 1 kton liquid argon
    - BooNE-X: 1-2 kton oil/scint



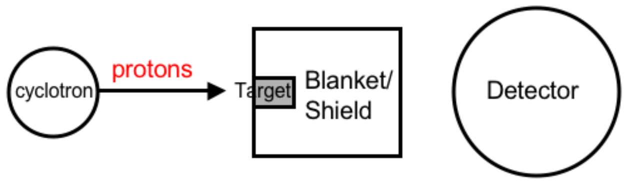
- Pion decay-at-rest beam
  Protons into dump
  $\rightarrow \pi^+ \rightarrow \nu_\mu\ \mu^+ \rightarrow e^+\ \nu_e\ \bar{\nu}_\mu$
  - Spallation neutron facilities
    - OscSNS: at SNS facility
    - JPARC SN facility
  - Also, Project-X RCS option
  - Physics signals:
    - $\bar{\nu}_e$ appearance
    - ν_μ ^{12}C neutral current
    - ν_e disappearance

Other Physics:
- ν Coherent Scattering
- Supernova cross sections

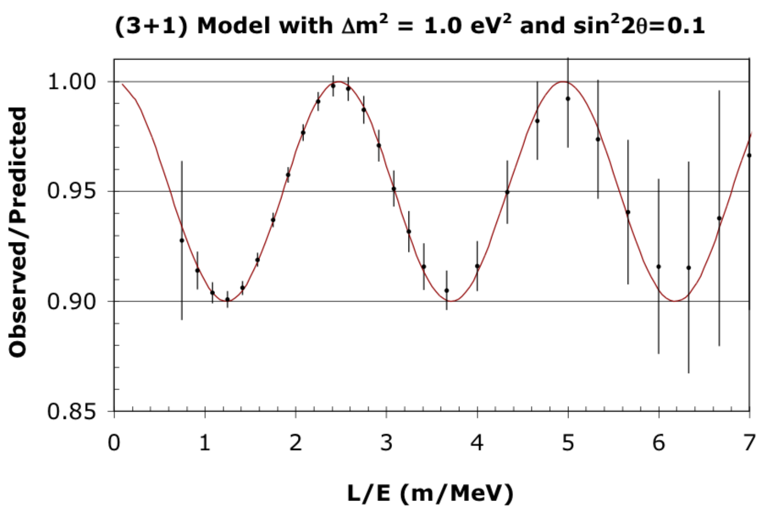


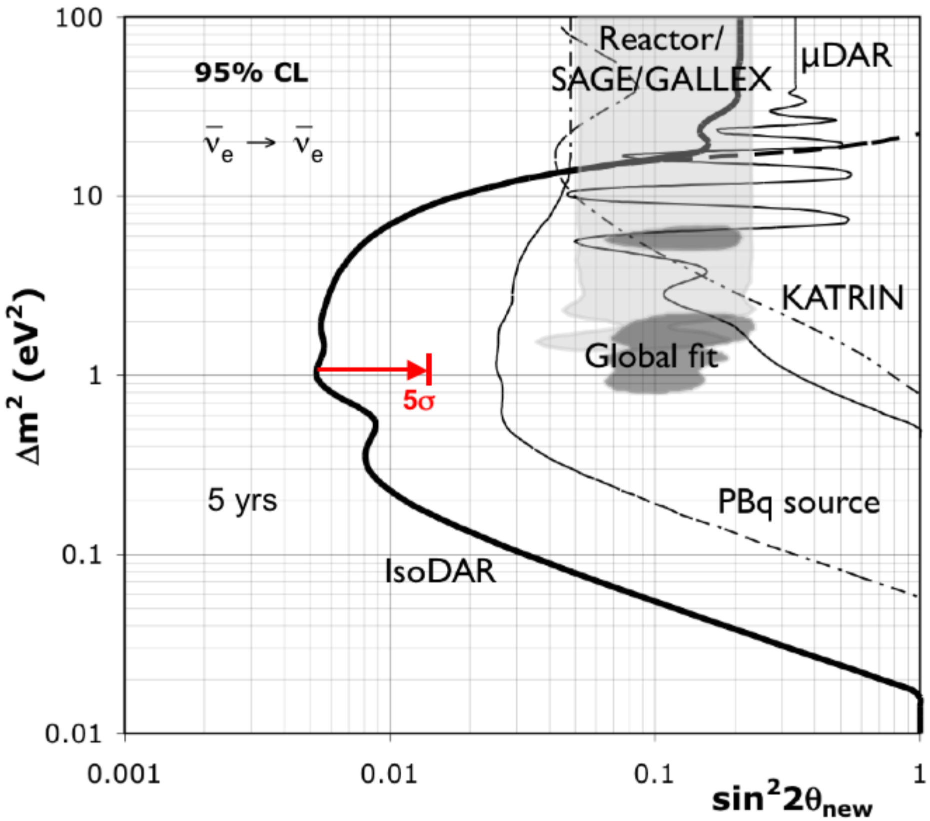
Improvements with Better Accelerator Sources (2)

- IsoDAR: Isotope Decay-at-rest beam (high intensity $\bar{\nu}_e$ source)



- p (60 MeV@10ma) into target $\rightarrow {}^{8}Li$
- ${}^{8}Li \rightarrow {}^{8}Be + e^{-} + \bar{\nu}_e$
  - Known $\bar{\nu}_e$ energy spectrum (mean 6.5 MeV)
  - Observe changes in the event rate as a function of L/E
    - ~160,000 IBD events / yr in Kamland





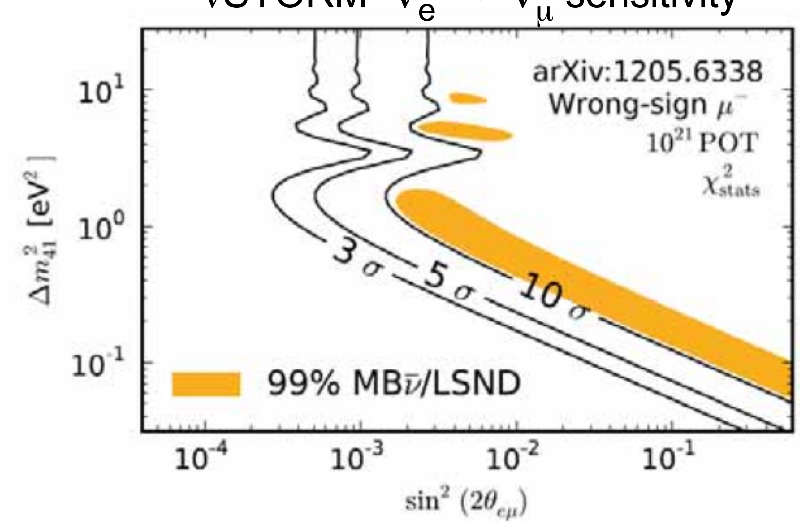
Possible Staging of Neutrino Factory

Neutrino factory has the advantages:

1. well collimated beam
2. known energy spectrum
3. easier detection of outgoing $\mu^\pm$ in $\nu_e \to \nu_\mu$ but need magnitized detector

- νSTORM: Short baseline neutrino factory enabling a definitive search for sterile neutrinos
- L3NF: An initial long baseline neutrino factory, optimized for a detector at Homestake that exceeds the capabilities of conventional superbeam technology.
- NF: A full intensity neutrino factory ultimate source to enable precision CP violation measurements

νSTORM $\nu_e \to \nu_\mu$ sensitivity

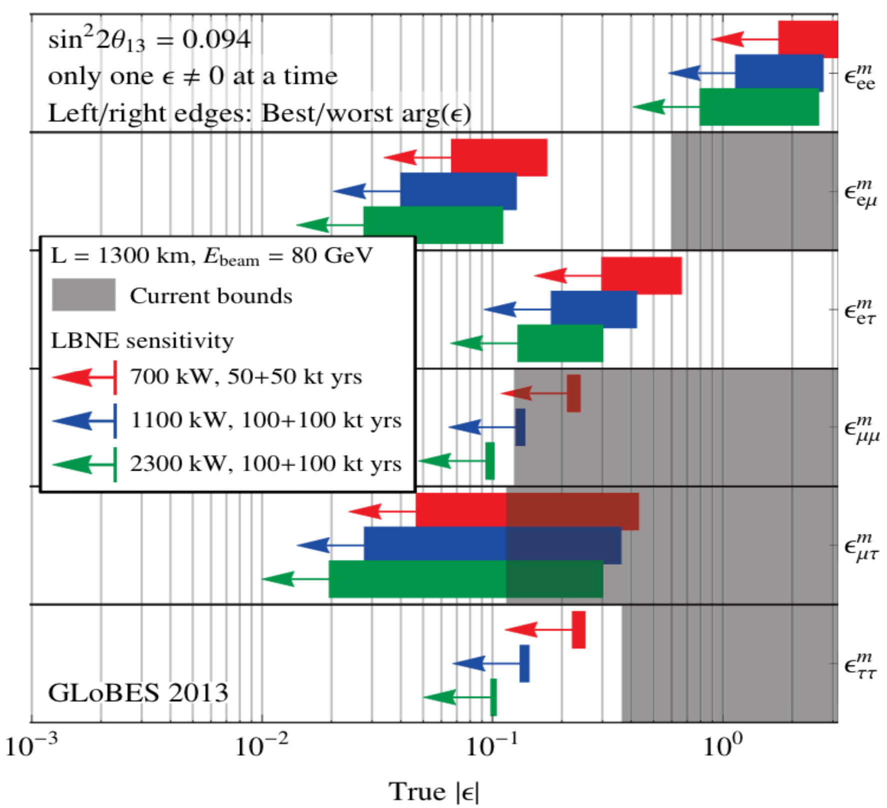


System	Parameters	Unit	νSTORM	L3NF	NF
Performance	stored μ+ or μ-/year		8×10^{17}	2×10^{20}	1.25×10^{21}
	ν_e or $\nu_\mu{}^*$ to detectors/yr		3×10^{17}	9.4×10^{19}	5.6×10^{20}
Detector	**Far Detector**	**Type**		**Mag LAr**	**Mag LAr**
	Distance from ring	km	1.5	1300	1300
	Mass	kT	1.3	10	30?
	magnetic field	T	2	0.5?	0.5?
	Near Detector	**Type**	**Liquid Ar**	**Liquid Ar**	**Liquid Ar**
	Distance from ring	m	50	100	100
	Mass	kT	0.1	1	2.7
	magnetic field	T	No	No	No

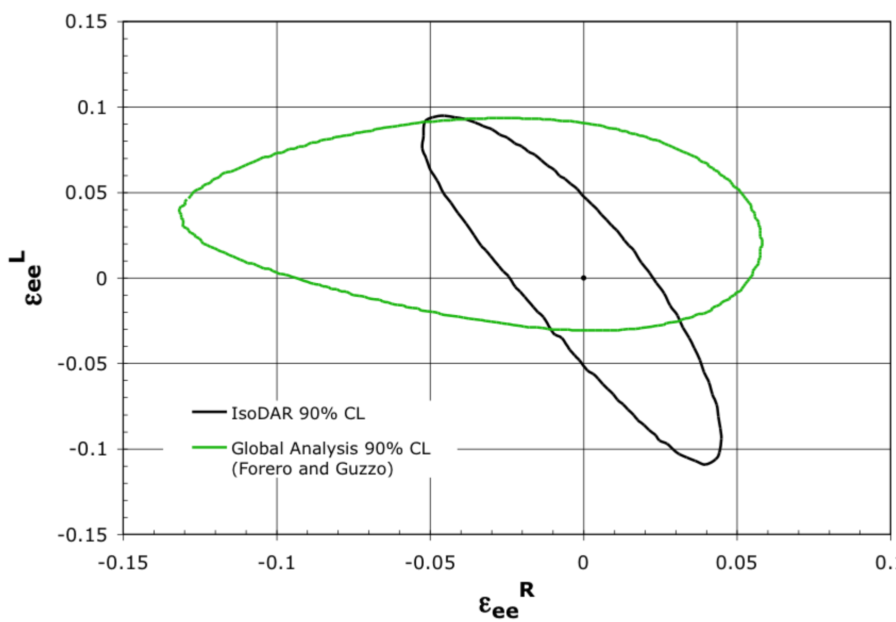
Non-Standard Neutrino Interactions

- Non-standard neutrino interactions (NSI) would alter matter effects in long baseline neutrino oscillation measurements
  - LBNE with Project-X has good baseline and statistics

NC NSI discovery reach (3σ C.L.)

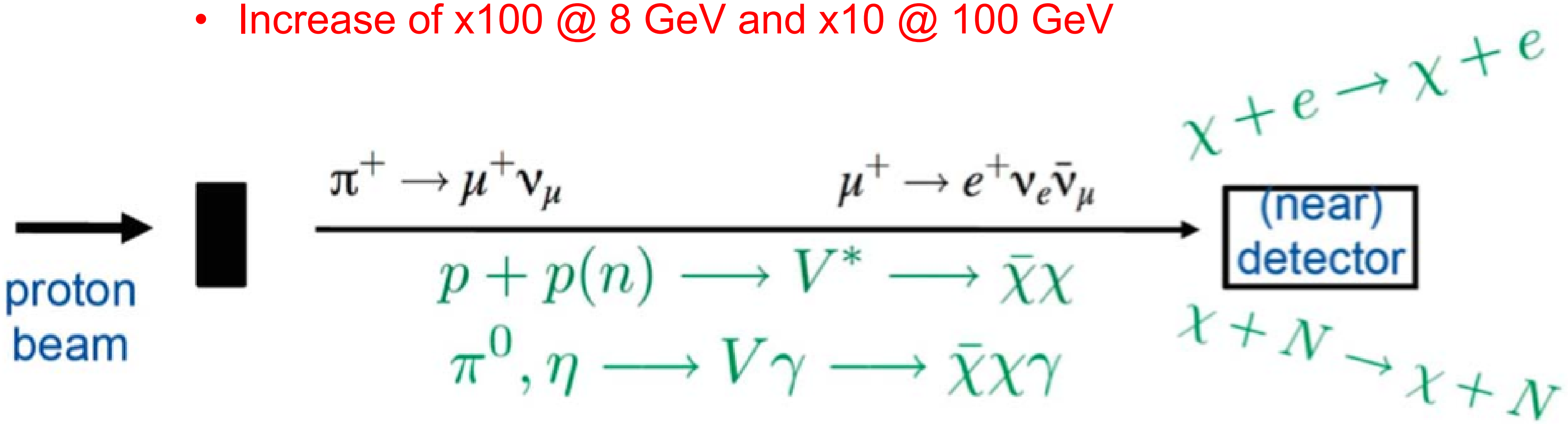


- Precision neutrino-electron scattering can also probe NSI since it is a well-understood Standard Model process
  - An IsoDAR cyclotron experiment at Kamland would have good statistics for $\bar{\nu}_e + e \rightarrow \bar{\nu}_e + e$



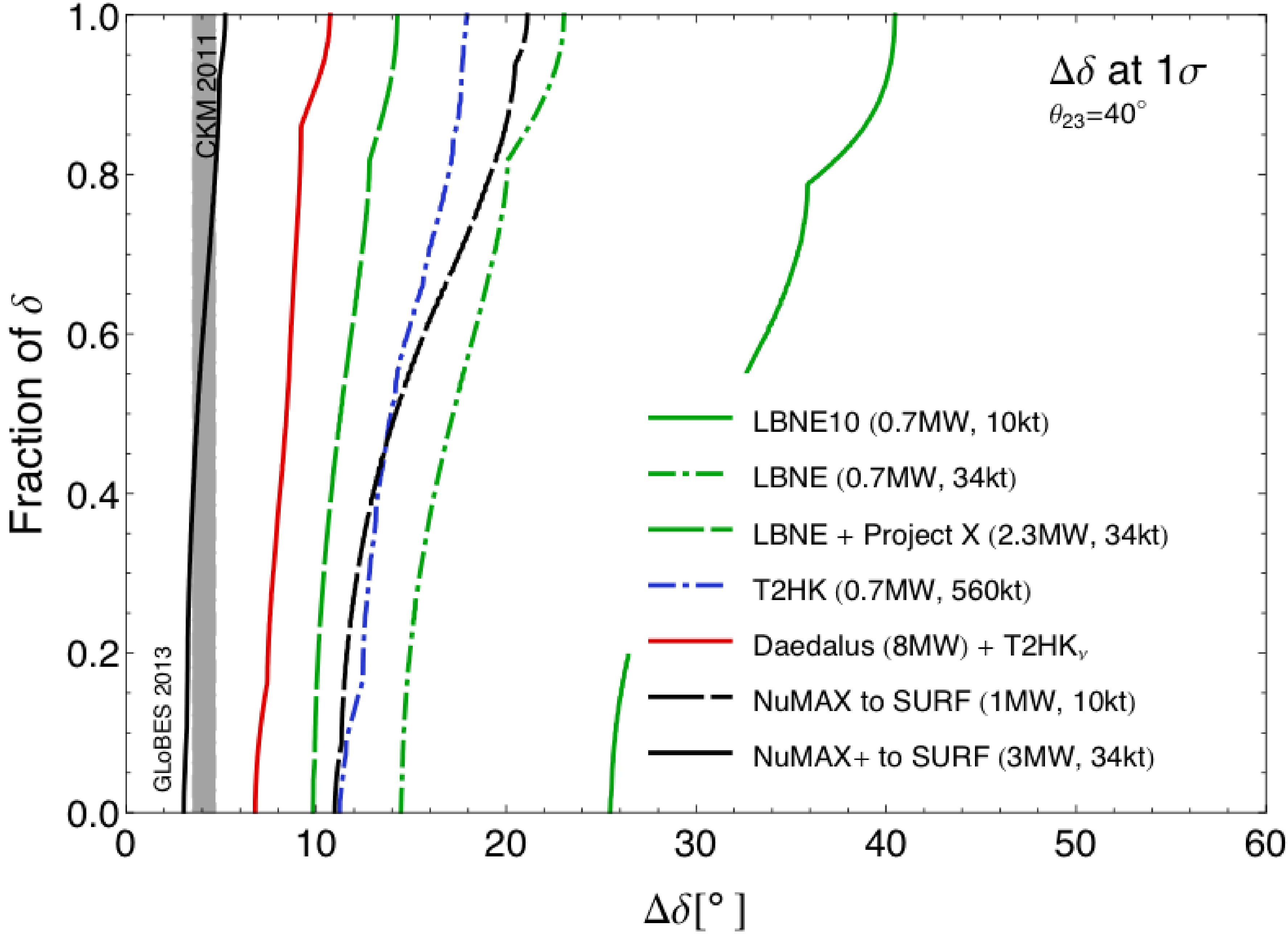
Searching for Exotic Particles with Short-baseline Experiments

- Short baseline experiments are a good tool for exotic particle searches including axions, dark gauge bosons, and WIMPs
  - A "portal' to the dark sector is dark photon mixing with normal photons and π^0 / η^0 decays to photons can produce "dark-sector" particles
  - Best to run in a "beam-dump" mode (no decay region) to surpress the convential neutrino backgrounds from pion and muon decay.
    - Not compatible with regular neutrino running - so need dedicated running
  - Intensity and energy are key parameters that could be significantly improved with various stages of Project-X
    - Increase of x100 @ 8 GeV and x10 @ 100 GeV



End of Part 1
Physics Opportunities

Backup Slides



Δδ at 1σ
θ23=40°
Fraction of δ
Δδ[°]
CKM 2011
GLoBES 2013
LBNE10 (0.7MW, 10kt)
LBNE (0.7MW, 34kt)
LBNE + Project X (2.3MW, 34kt)
T2HK (0.7MW, 560kt)
Daedalus (8MW) + T2HKν
NuMAX to SURF (1MW, 10kt)
NuMAX+ to SURF (3MW, 34kt)
0.0
0.2
0.4
0.6
0.8
1.0
0
10
20
30
40
50
60